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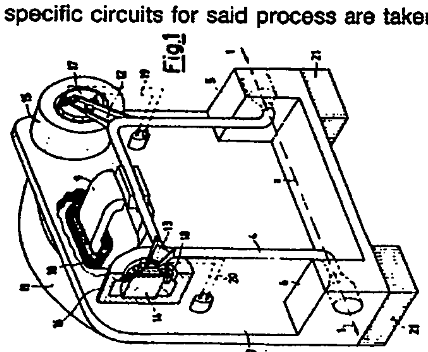
㊴ Improved process for the measurement of weight flowrates and related devices.

㊼ The process for the measurement of the weight flow-rate of an outflowing fluid inside a pipe made oscillate by an impulse-generating unit at a certain frequency, and at a constant and controlled amplitude, consists in making said pipe constantly oscillate exactly at its twisting resonance frequency, in counteracting the oscillation of the pipe with at least a couple of brakes, performing a braking action which is proportional to the pipe shifting speed, and has an intensity larger than the intensity of the Coriolis forces acting on the pipe, in detecting the pipe shifting in the two symmetrical points of the pipe relatively to its middle, wherein the largest twisting deformation occurs, and finally in determining the differences in the amplitudes of the above-said two shifts, which difference is directly proportional to the desired flow-rate, but on condition that all disturbances have been eliminated.

Furthermore, different forms of practical embodiment of measurement instruments operating according to the above-said process, as well as specific circuits for said process are taken into consideration.



EP 0 272 758 A2

"IMPROVED PROCESS FOR THE MEASUREMENT OF WEIGHT FLOW-RATES AND RELATED DEVICES"

The present invention is concerned with a new measurement process which, by introducing a linear relationship between the weight flow-rate of a fluid outflowing through an oscillating pipe, and the considerable difference in amplitude between the oscillations of the ends of said pipe, caused by the twisting deformation of the tube due to the Coriolis effect, makes it possible an efficacious, easy and precise measurement of the above said weight flow-rate to be achieved, even in case of extremely small flow-rates; furthermore, by making it possible the amplitude of the flexural oscillation of the pipe to be reduced, the present invention minimizes the mechanical stress undergone by said pipe, whilst the large magnitude of the produced twisting excursions makes the pipe particularly insensitive to the seismic disturbances.

The invention is also concerned with the devices for practicing the above said measurement process.

From the prior art, process and devices are already well known, for determining the weight flow-rate of an outflowing fluid inside a duct or pipe, which is angularly revolved in a reciprocating mode, by measuring the twisting moment generated by the Coriolis forces, starting from the ancient devices for mass flow-rate measurement of gyroscopic type, which are precisely based on the measurement of the Coriolis forces.

The first device the present invention can be more directly related to, was patented in 1964 by A.J. Sipin (U.S. patent No. 3,355,944 issued in 1969), and consists of a pipe to which a portal shape is given, reciprocated around an axis coincident with the alignment of the input and output ends of the pipe, and provided with strain-gauge type means for measuring the deformations caused by the Coriolis forces.

The above said motion is achieved both by means of a motor, and by means of an electromagnet, and the amplitude of the oscillations is kept controlled (cfr. claim 5) by controlling the average amplitude of two speed signals obtained by means of two sensors of electromagnetic type provided along the sides of the portal, whilst the measurement of the flow-rate is derived from the difference between these two signals. In said patent, it is also claimed (see specifically claim 10) that the frequency of oscillation is the resonance frequency of the system.

Also in 1964, same A.J. Sipin patented (U.S. patent No. 3,329,019, issued in 1967) also a completely rectilinear geometry of the pipe, made laterally oscillate by the same means, and with the same amplitude control as of the prior case, i.e., carried out by means of two speed sensors located on one side, and on the other side, relatively to the middle point of the pipe. Also in this practical embodiment, the operation at the frequency of resonance of the system is considered (see claim 6).

The reasons why the above said devices did not function in practice are the substantially extremely low values of the Coriolis forces, and of the relevant deformations both relatively to the impulse forces applied to make pipe oscillate, and to the frictions of the mechanisms and of the couplings. Then, there is the mistake, or, better, the inexactness of deriving the flow-rate signal by starting from the difference between two speed signals, when, on the contrary, the flow-rate signal can be correctly deduced only from the phase difference between the two speed signals, whose amplitude remains constant under all normal conditions, except for a very special condition, which is, precisely, the object of the present invention.

In fact, at the flexural resonance frequency, the flexural impulse force of the pipe produces a shift of the same pipe in quadrature relatively to the same force; on the other hand, the Coriolis force, always in quadrature relatively to the above said flexural shift, produces, in its tun, a twisting shift in the tube, which is in phase with the same force, with the oscillation frequency being smaller than the twisting resonance frequency, and is therefore in quadrature relatively to the twisting shift of the pipe; the end shift of the pipe, which is the vectorial sum of the two shifts in quadrature relatively to each other, will therefore show, relatively to the twisting shift of the pipe, a phase difference, to the determination of which the measurement of the weight flow-rate has to be reconducted.

In order to obviate the above-said functional limits, improving variants have been developed, which led to the realization of commercial products.

The first patent which supplies a solution for the Sipin's concept is by Bruce M. Cox (U.S. patent No. 4,127,028, issued in 1978), which identifies, first of all, that the value of the weight flow-rate is defined by the phase delay between the two signals obtained from the two sensors, and not by a difference in their amplitude (see, on this point, Figure 2 of said U.S. patent), and furthermore increases the signal/noise ratio by giving the pipe a racket shape, such to decrease the twisting stiffness, with the result that, by lowering the frequency of twisting resonance until it becomes close to the flexural resonance frequency, the small Coriolis forces can generat larger deformations, thanks to the smaller twisting stiffness of the system. Then Cox couples two equal pipes, through which a same fluid flows, and makes them vibrate in mutually opposite mode, such to prevent interactions of vibrations with the supports of the device, in order to reduce

the vibration energy and to improve the precision, in as much as the signal is doubled, and furthermore the system becomes less sensitive to the external vibrations.

The main limit affecting the Cox device is that, by approaching the frequency of twisting resonance to the own frequency of flexural or longitudinal resonance, or making said frequency of twisting resonance coincide with said own frequency of flexural or longitudinal resonance, and hence approaching the frequency of oscillation of the system to the twisting resonance frequency, it's true that an increas in sensitivity is obtained, but the relationship between the angles of phase displacement, and the Coriolis forces does no longer result linear, and this phenomenon the more relevant, the more the vibration coincides with the twisting resonance frequency in correspondence of which the maximum in sensitivity occurs.

Under these conditions, both the small Coriolis forces, and small unsymmetries cause an increasingly larger twisting oscillation, whose effect is that the Coriolis forces are magnified in their turn, whilst the end equilibrium under resonance conditions is obtained with the dispersion of both aerodynamic energy, which varies according to a square law, as a function of the shifts, and mechanical energy, with pipe hysteresis cycles, which also result in risks of fatigue breakages.

On the other side, under the conditions of twisting resonance, besides the non-linearity, also a phase shift occurs between the movement phase and the phase of the Coriolis forces. In fact, the twisting deformations due to the Coriolis forces, from being in phase with said forces, shift in phase, up to reach a phase advance of 90°, so that the amplitudes of the two signals become different, and their phase delay decreases down to zero. But, in as much as Cox uses as the signal the difference in phase between the two movements, of equal amplitude, of the position sensors installed on the pipes, as it can also be clearly deduced from Figure 2 of above U.S. patent, it is consequently clear that Cox device shall vibrate at frequencies which are relatively far away from the twisting resonance, and therefore the actual extremely large potential amplification is not taken advantage of, as it can be obtained, on the contrary, by operating at a frequency precisely equal to the twisting resonance frequency.

Another practical embodiment disclosed in U.S. patent No. 4,187,721 issued in 1980 to James E. Smith, functionally improves the invention disclosed by Sipin.

In said patent, Smith states the need of making a U-shaped pipe operate exactly, and only, at the flexural resonance frequency, because at this frequency only, the forces necessary to supply the impulse force to the pipe are so small, as not to interfere with the extremely small Coriolis forces, and furthermore he states that the own flexural resonance frequency must be smaller that the twisting resonance frequency, precisely in order to prevent the operating anomalies, as described above in connection with Cox patent, from occurring.

With the contrivances by Smith, the measured value results to be a really well linear function of the flow-rate, but the limit anyway remains, that signals of infinitesimal magnitude have to be processed, which require an extremely sophisticated electronics, anyway with problems of stability of the meaured values, in the nearby of zero flow-rates, and with problems of disturbances of seismic type.

The purpose of the present invention is precisely obviating the above-said drawbacks, and therefore providing a process, and a corresponding device, which make it possible the weight flow-rate to be efficaciously measured through the effects of the Coriolis forces, with the possibility being exploited as extensively as possible, of having very large signals by making the system oscillate exactly at the twisting resonance frequency, without this latter having to necessarily coincide with the own flexural oscillation frequency of the system.

On the other side, by means of said process, due to the considerable magnitude of the signal which can be obtained when the pipe is forced to oscillate in flexural mode at a frequency equal to the twisting frequency thereof, besides achieving a substantially improved performance, in particular at the small flow-rates, and a lower sensitivity to the seismic disturbances, without having to resort to the expensive doubling of the oscillating pipes as it results from the prior state of the art, and besides rendering functional, and really practicable, in particular in case of medium and large flow-rates, also the use of a rectilinear pipe, like the type disclosed by Sipin, making it operate at an oscillation frequency which coincides with the second harmonic, the considerable advantage is also achieved that the weight flow-rate flowing inside the pipe results to be linearly proportional to the amplitude of the twisting shifts of the same pipe. In fact, at the twisting resonance frequency, the flexural impulse force supplied to the tube produces a flexural shift of the same pipe, which shows a phase difference of 180° (in opposition) relatively to the above-said force; on the other side, the Coriolis force, always in quadrature relatively to the above said flexural shift, produces, in its turn, a twisting shift of the pipe, which, with the system vibrating at its twisting resonance frequency, results to be in quadrature relatively to the same force, and is hence in phase with the flexural shift; the resulting end shift of the pipe is still the vectorial sum of the above-said two shifts which, by being in phase, are

simply added to each other, and hence the simple difference between this latter shift. and the flexural shift suppli s a measure for th twisting shift, which is linearly proportional to the weight flow-rate to be determined.

Furthermore, as the twisting shift of the pipe is in quadrature relatively to the Coriolis forces, it derives from this that sad twisting shift will be maximum when the Coriolis forces are zero, and vice-versa, and it will hence be maximum at the limits of the flexural shift and zero at the centre thereof, as it is shown in Figure 3, with the result that at an end an A shift will occur, which is larger than the B shift at the other end, viz., Coriolis forces will occur, which are larger in A (fluid outlet) and smaller in B (fluid inlet), and, indeed, the above-said difference for determining the value of the weight flow-rate is actually reconducted to the difference, A - B, in amplitude of the oscillations between the two vertices of a portal-shaped pipe, or between the two sides of a rectilinear pipe, in two intermediate points between the middle and the two ends of the same pipe.

Now then, the above result is substantially achieved not only by forcing, e.g., by an impulse-force-generating magnet, the pipe to oscillate at its twisting resonance frequency, but also by using two magnetic brakes with differentiated braking effect, proportional to the oscillation speed of the pipe, and of a magnitude at least equal to that of the Coriolis forces, as it will be better clarified in the following, which have the double purpose of generating, with their unbalancing, a signal of the same type, and with the same phase, as the Coriolis forces, which allows the pipe to oscillate in a twisting mode also when the weight flow-rate is zero, and hence the Coriolis forces are zero, i.e., summing-up, enables the circuit for the automatic search for the frequency peak to correctly operate also around zero value, and, above all, makes it possible to prevent the amplitude of the twisting shift, which is increasing due to the effect of the resonance, from exceeding the limit value compatible with a correct operation, i.e., that prevents a crossing of movements from occurring, with the reversal of the motion of B relatively to A, as it is shown in Figure 4, in that, a further typical need required by the instant invention for an actually linear proportionality to be obtained between the (A-B) amplitude of the twisting deformation of the oscillating pipe and the weight flow-rate is, as it will be better clarified in the following, that the amplitude (A + B) of the flexural oscillation of the pipe is always constant or controlled, and (see specifically Figure 3), that the shifts of A and B amplitude are always in phase reatively to each other, what occurs only under conditions of perfect twisting resonance, and only whenever neither mechanical misalignments, nor unsymmetries occur in the elastic characteristics of the pipe, and in the point of application of the impulse force.

The main problem consists in making the pipe vibrate in flexural mode, and at a frequency different from its spontaneous resonance frequency, with said frequencty being exactly maintained equal to the peak of twisting resonance frequency.

The solution was obtained by means of an electronic circuit which, according to a characteristic of the present invention, searches for, and maintains, the twisting frequency obtained by maximizing the amplitude of the measurement signal (A-B), viz., determines, by increasing, by successive steps, the frequency of the impulse force supplied to the pipe, the frequency of flexural oscillation to which the maximum twisting ocillation, and hence, the highest (A-B) value, corresponds.

Then, according to a variant of the present invention, the circuit makes it possible to find out, and maintain, the twisting resonance frequency, also in the presence of variable flow-rates.

Furthermore, according to another characteristic of the present invention, other electronic circuits are provided, in order to filter, in an original way, the signals corresponding to (A + B) and (A-B) quantities, in order to purge them from the disturbances, removing the spurious harmonics and only retain the components which are in perfect quadrature with the Coriolis forces, and therefore surely in phase with one another, in order to keep constant the (A + B) amplitude of the flexural oscillation, and in order to compensate for the above-said differential action of the brakes, such that when the flow-rate is zero, a zero outlet signal is achieved.

Finally, according to a further advantage of the present invention, the measurement system is made immune from the seismic disturbances, with a considerable saving in costs, and without the usual complication of the doubling of the pipes, by simply mounting it on an elastic support, which thus enables it to oscillate in opposition of phase relatively to the oscillation of the pipe, and hence not to interact with the support plane.

On the other side, the above-said necessary conditions for a correct operation of the measurement instrument derive from a precise mathematical analysis of the behaviour of a pipe oscillating at the twisting resonance frequency.

In order to simplify the tr ating, th oscillating system has been reduced to two articulations only (see Figures 5 and 7), which, in case of a "U"-shaped, or portal-shaped pipe (see figure 6), identify the flexural mode and the twisting mode of movement, whilst in case of a rectilinear pipe (see Figure 8), identify the

oscillation relevant to the first harmonic, and to the second harmonic. The masses M_A and M_B have been concentrated, in their turn, in two points (see still Figures 5 and 7), and only the motion of these two points is analysed. These masses M_A and M_B concentrate the weight of the pipe, and of all of the rigid components connected with it for the supply of the impulse force causing the pipe motion, for the braking and for the monitoring of the movement, whist the mass m represents the efficacious value, referred to the considered point, of the mass of fluid flowing through the pipe according to the direction shown by the arrows 1 (see Figures 6 and 8), and concerned by the Coriolis forces C_A and C_B.

Still to the two points taken into consideration, the elastic constants are referred, which relate to the flexural motion, K_{fA} and K_{fB}; and the elastic constants are referred, which relate to the twisting motion, $K_{tA}$and K_{tB}; furthermore, to the same two points, two forces, F_A and F_B, are considered as separately applied, which cause the system to forcedly oscillate, and which, in reality, can also be replaced by one single force F applied to the centre of symmetry of the pipe. Finally, also the viscous action and the aerodynamic action are referred to the two above-said point, with two forces proportional to the speed multiplied by the brake dampening coefficients, respectively G_A and G_B, and with two further forces, proportional to the square speed, multiplied by the coefficient $C_{dA} = C_{dB} = C_{dC}$, which defines the aerodynamic resistance. Furthermore, in as much as the considered movements are of very small magnitude, the possibilities of losses due to the cycle of hysteresis of the material of the pipe, or due to the dynamic effects of the vortexes induced in the fluid contained in the pipe have been neglected.

Whilst in the portal-shaped pipe (see Figure 5), the flexural movement is simplified, up to be considered as a revolution around the X axis, in the rectilinear pipe, wherein the schematization has been forced by means of hinges, sliders and slides (see Figure 7), such to have the same elements, the same constants, and, hence, the same relationships which describe the motion, the flexural movement takes place by the masses M+m as a revolution around the two Z_A and Z_B axes passing through the end hinges. Then the motion of the two masses taken into consideration takes place both in the portal-shaped pipe case, and in case of the rectilinear pipe, always according to the Y axis.

We specify furthermore that by "A" indicated is the maximum shift, relatively to the axis of rest, of M_A+m mass, by "B" indicated is the maximum shift, relatively to the axis of rest, of M_B +m mass (on this regard, see Figure 3), and that, for the sake of simpleness, the supply of the impulse force to the system is supposed to take place by means of the application of two forces $F_A$and F_B having a sinusoidal law, or by means of a single force F, always of

$F = F_o.\sin wt$

type, applied in the centre of symmetry, even if from a practical standpoint, an acceptable performance could also be obtained by means of wave shapes different from sinusoidal wave, anyway with the drawback that the motion would be dirtied by the superimposition of all of the harmonics contained in the impulse-supplying force.

Now, the motion equations which describe the equilibrium between the excitation forces F_A and F_B and respectively the forces of inertia of the system, the forces due to the viscous friction of the magnetic brakes, the Coriolis forces, the forces due to the aerodynamic friction and the elastic reactions result, respectively:

$$F_A = -\ddot{Y}_A(M+m) - \dot{Y}_A(G-\Delta) + 2mV\frac{\dot{Y}_A}{R} - \dot{Y}_A^2 C_d - Y_A K \qquad (1)$$

$$F_B = -\ddot{Y}_B(M+m) - \dot{Y}_B(G+\Delta) - 2mV\frac{\dot{Y}_B}{R} - \dot{Y}_B^2 C_d - Y_B K \qquad (2)$$

wherein:

G represents the average value of the coefficient of dampening of the magnetic brakes, viz., the value:

$(G_A + G_B)/2$

and Δ represents their half-difference, i.e., the value:

$(G_B - G_A)/2$

so that the term $(G-\Delta)$ is actually equal to G_A, and $(G+\Delta)$ is equal to G_B, i.e., the above in order to show

that the two dampening coefficients G_A and G_B are actually structurally realized in different ways, with the larger coefficient (G_B) being on the side of fluid input, and the smaller coefficient (G_A) being on the fluid output side: in such way, the brakes generate forces different from each other, and in phase with the Coriolis forces, and the torque deriving from their difference has, from a physical standpoint, the same effect as of a flow rate;

R represents the radius of revolution of the mass $\underline{m}$ (see Figures 5 and 7);

V represents the speed of flow through the pipe of the fluid particle $\underline{m}$;

K indicates the total elastic constant, and the term

$$2\,mV\,\frac{\dot{Y}}{R}$$

indicates the Coriolis forces C_A and C_B, wherein $\dot{Y}/R$ represents the angular speed of the point under consideration, and mV is a term proportional to the weight flow rate flowing inside the pipe.

In order to evidencing the forces which generate the twisting motion, it is advantageous to decompose each motion into its respectively flexural and twisting components, viz.:

$$Y_A = \frac{Y_A + Y_B}{2} + \frac{Y_A - Y_B}{2}$$

$$Y_B = \frac{Y_A + Y_B}{2} - \frac{Y_A - Y_B}{2}$$

By decomposing also the elastic reactions into the two contributes, we obtain:

$$Y_A K = \left(\frac{Y_A + Y_B}{2} K_{fA} + \frac{Y_A - Y_B}{2} K_{tA}\right) \qquad (3)$$

$$Y_B K = \left(\frac{Y_A + Y_B}{2} K_{fA} - \frac{Y_A - Y_B}{2} K_{tA}\right) \qquad (4)$$

By subtracting equation (2) from equation (1), after introducing equation (3) and equation (4), and imposing that

$K_{fA} = K_{fB}$

and that

$K_{tA} = K_{tB} = K_t$,

we obtain a relationship between the forces which condition the twisting motion, while the terms which describe equal, in-phase forces disappear, and which hence relate to the flexural motion:

$$0 = -(M+m)(\ddot{Y}_A-\ddot{Y}_B) - G(\dot{Y}_A-\dot{Y}_B) + \Delta(\dot{Y}_A+\dot{Y}_B) + \frac{2mV}{R}(\dot{Y}_A+\dot{Y}_B) -$$

$$- C_d(\dot{Y}_A{}^2-\dot{Y}_B{}^2) - K_t(Y_A-Y_B) \qquad (5)$$

Under these conditions, it is possible to admit that the resulting motion law is sinusoidal of type:

$Y_A = A \sin wt$

$Y_B = B \sin (wt + \vartheta)$,

wherein ϑ is the phase delay between the two movements.

This phase delay ϑ is at the basis of all of the instruments for carrying out measurements of weight flow rate, which have been practically embodied up to date, which all operate with a flexural vibration centered in frequence on the first flexural resonant. Under those conditions, in fact, if the system is mechanically symmetrical, the angle ϑ, even if is extremely small, is perfectly linear with the weight flow rate of the outflowing fluid, whilst the amplitudes A and B of the two movements are equal. However, in the present case the angle ϑ is supposed to remain zero with varying flow rate values, and hence we'll have:

$Y_A = A \sin wt$

$Y_B = B \sin wt \qquad (6)$

As a consequence, the speeds and accelerations of the two points will be, respectively:

$\dot{Y}_A = A w \cos wt \qquad \ddot{Y}_A = - A w^2 \sin wt \qquad (7)$

$\dot{Y}_B = B w \cos wt \qquad \ddot{Y}_B = - B w^2 \sin wt$

Then substituting equations (6) and (7) into equation (5), we have:

$0 = (M+m)(A-B) w^2 \sin wt - G(A-B) w \cos wt -$

$-\Delta (A+B) w \cos wt + \frac{2mV}{R} (A+B) w \cos wt -$

$-C_d(A+B)(A-B) w^2 \cos^2 wt - K_t(A-B) \sin wt$

from which:

$$A-B = \frac{(A+B)(2mV/R + \Delta)}{G + \left[K_t - w^2(M+m)\right](\tan wt)/w + (A+B)C_d w^2 \cos^2 wt} \qquad (8)$$

If we furthermore suppose that the braking effect G of the magnetic brakes is considerably predominant as compared to the aerodynamic friction, which can be furthermore considered as negligible, also due to the fact that the the flexural movement has a very small amplitude (A+B), the equation (8) is reduced to:

$$A-B = \frac{(A+B)(HQ + \Delta)}{G + \left[K_t - w^2(M+m)\right](\tan wt)/w} \qquad (9)$$

wherein the weight flow rate Q has been introduced, which is linearly proportional, according to the constant H, to the Coriolis term 2mV/R.

We observe now that if the oscillating system is made specifically oscillate at its twisting resonance frequency, equal to

$$w = \sqrt{\frac{K_t}{M+m}}$$

also the second term appearing in the denominator of equation (9) becomes zero, so that said latt r equation is reduced to:

$$A-B = \frac{(A+B)(HQ + \Delta)}{G} \qquad (10)$$

From equation (10), we observe that a linear proportionality exists between the weight flow rate Q outflowing through the oscillating system, and the amplitude of the twisting oscillation (A-B) on condition that the amplitude of the flexural oscillation (A+B) is maintained constant and controlled, with its effect being measured and entered in the computation.

On the other hand, from the above-said equation, we observe that the smaller G, the larger the twisting shift (A-B), and hence the larger the effect of the Coriolis forces, but one should remind that G cannot be too small, because (A-B) would then become too large, and the crossing of the movements would occur, with the consequent reversal of the motion of B relatively to A, as already mentioned and illustrated in Figure 4, with a consequent loss of linearity between the weight flow rate and the twisting shift. In as much as this reversal begins when the twisting shift B becomes zero, i.e., when we have

$$\frac{A-B}{A+B} = 1,$$

the condition which must be fulfilled is that:

$$\frac{A-B}{A+B} < 1$$

and, consequently, from (10) we have that:

$$\frac{A-B}{A+B} = \frac{HQ + \Delta}{G} < 1.$$

from which:

$G > HQ + \Delta$

i.e., the system is linear only if the action of the magnetic brakes generates forces larger than the forces generated by the Coriolis effect.

Summing up, a linear proportionality is obtained between the amplitude of the twisting oscillation (A-B) and the weight flow rate Q, so that this latter can be determined by simply measuring the shifts of the pipe in the two points taken into consideration, on condition that the preset hypotheses are fulfilled, i.e., that unsymmetries do not exist in mechanical characteristics (unequal masses), or in the elastic characteristics ($K_f$and K_t) of the system, or in the application of the pulsating force(s), which, by generating disturbances in quadrature relatively to the Coriolis forces, would tend to displace in phase the two shift signals A and B, taking away linearity from the measurement system, and that, furthermore, the impulse-supplying forces are sinusoidal, without harmonics in phase with one another (ϑ = 0), that implies, summing up, that the two shift signals A and B result in phase with each other, and lacking in spurious harmonics; that the frequency of oscillation is exactly, and exclusively equal to the frequency corresponding to the twisting resonance of

th syst m, that th amplitude of th flexural oscillation (A + B) remains constant or controlled, and, finally, that the oscillation motion is counteracted by two brakes applying different braking effects, ans whose total action is considerable, and always larger than the action caused by the Coriolis effect.

On the other hand, one should remind that, instead of the shifts of the pipe measured, for example, by means of two Hall probes, in the two points taken into consideration, also the speeds of the two points, measured by means of two speed sensors, can be considered, in as much as the differential variable of the two signals becomes simply proportional to w(A-B), while an automatic control means which keeps constant the sum of the two signals practically accomplishes the constance of w(A + B) product, and hence the validity of equation (10) is kept unchanged, but with said equation being expressed in the shape:

$$w\,(A-B) = \frac{w\,(A+B)\,(HQ + \Delta)}{G}$$

The use of the speed sensors involves however two advantages; a first advantage of mainly practical character, due to the easiness with which the sensors can be incorporated in the same brakes, and a second advantage, based on the fact that the automatic control means, which keeps constant the w(A + B) product, even if is substantially equivalent to the control of the only amplitude (A + B), has the advantageous characteristic of rendering invariable the values of the Coriolis forces with varying $\underline{w}$, due to, e.g., a change in temperature, which causes a change in the elastic constant K_t of the metal of the pipe

$$\left(w = \sqrt{\frac{K_t}{M + m}}\right)$$

and this simplifies the problem of keeping low the thermal disturbances which, with the term HQ remaining constant, substantially depend on the possible not constancy of Δ and of G with varying temperature.

The invention is now better explained by referring to the hereto attached drawings, which display preferred forms of practical embodiment, given for only exemplifying, and not limitative, purposes, in that technical, technological and structural variants can be always supplied within the scope of the present invention.

In said drawings:

Figure 1 shows a partially sectional perspective view of a flowmeter, or flow rate meter, with a portal-shaped pipe, operating according to the teachings of the present invention;

Figure 2 shows a partially sectional perspective view of a flowmeter, with a rectilinear pipe, also operating according to the teachings of the present invention;

Figure 3 is a diagram showing, as already said, the flexural-twisting shifts of the pipe used according to the present invention;

Figure 4 is a diagram showing, as already said, the crossing of the movements of the ends of the pipe, due to an excessive twisting movement;

Figure 5 shows the mechanical schematization made for the mathematical study of the behaviour of a portal-shaped pipe oscillating at the frequency of twisting resonance;

Figure 6 shows the instantaneous behaviour of the Coriolis forces C_A and C_B acting on the two sides of the oscillating portal-shaped pipe;

Figure 7 shows a diagram analogous to that of Figure 5, but made for a rectilinear pipe;

Figure 8 shows the instantaneous behaviour of the Coriolis forces C_A and C_B, as well as the oscillations relevant to the first harmonic 2, and to the second harmonic 3 of a rectilinear pipe;

Figure 9 shows, in a single block diagram, the electronic control circuits for a flowmeter according to the invention;

Figure 10 shows a variant of the block diagram of Figure 9, to make due allowance for the variability of th flow rate;

Figure 11 shows the behaviour with tim of the function cos(i.π/3), discretized according to the invention by th function cos(2πt/T);

Figure 12 is a chart showing the curve of correlation between the integrated quantity U and the frequency of oscillation f with a constant flow rate, as well as the frequency increases which must be supplied in the search for the twisting resonance frequency;

Figure 13 is a chart showing the behaviours with time, correlated with one another, of the quantities necessary for the search for the twisting resonance frequency with the flow rate being constant;

Figure 14 is a chart showing the curves of correlation between the integrated quantity U and the frequency of oscillation f at different values of flow rate, as well as the frequency increases which must be supplied in the search for the twisting resonance frequency;

Figure 15 is a chart showing the behaviours with time, correlated with one another, of the quantities necessary for the search for the twisting resonance frequency with a variable flow rate;

Figure 16 shows a double-rectilinear-pipe flowmeter, it too operating according to the teachings of the present invention;

Figure 17 shows a perspective view, on an enlarged scale, of a detail of the flowstat of Figure 16.

Referring to the Figures, wherein corresponding elements have been indicated by same reference numerals, by 4 indicated is a portal-shaped pipe, fastened to, and rigidly hold with its two ends inside two shoulders 5 and 6 of a rigid support 7, through which the fluid 7, whose weight flow rate is to be measured, flows in the direction of the arrows 1.

Said pipe 4 is made oscillate around the axis X by an electromagnet 9, whose excitation coil 10 is fed with a determined voltage having a determined frequency, in particular the twisting resonance frequency of the system, supplied by the circuit system represented by the block diagram shown in Figure 9, and contained inside the box 11 fastened to the rear side of the support 7, which also supports the electromagnet 9. To the corners of the portal 4, two small brackets 12 and 13 are then fastened, to which the movable coils 14 of two electromagnetic brakes, respectively 15 and 16, are fastened, with the two electromagnetic brakes being in their turn fastened to the support 7.

Then, to each movable coil 14, applied is a speed sensor, or a Hall probe, respectively 17 and 18, which thus substantially measure the shifts of the corners of the portal, and, more precisely, respectively, the already mentioned quantities B and A, whose values are respectively sent to the inputs of the system of Figure 9, respectively through the leads 19 and 20. The two electromagnetic brakes 15 and 16 have furthermore braking effects which are different from each other, the larger of said two braking effects being the effect generated by the brake 15 provided at the inlet side of the pipe, to create a false Coriolis effect, which twists the pipe also in the absence of a flow rate. Finally, the whole equipment, or flowmeter, is mounted of supports 21 of elastic type, which render it immune from seismic disturbances.

The above said signals A amd B produced by the pipe - it is indifferent whether the pipe is of the portal type, or is a rectilinear pipe, as well as it is also indifferent whether they are position signals, rather than speed signals - and detected by the sensors 18 and 17, after being respectively amplified by the amplifiers 22 and 23 (see Figure 9), are then subtracted from each other in the node 24, and added to each other in the node 25, to have, at output 26, a signal corresponding to the quantity (A-B) and at the output 27 a signal corresponding to the quantity (A + B).

On the other hand, due to the almost total impossibility, from a practical viewpoint, of maintaining a perfect mechanical alignment in the flowmeter, in as much as this latter irremediably decays also just due to the simple and easy unsymmetrical fouling of the pipe, as well as due to the disordered vibrations which occur due to various and fortuitous causes, the above-said two signals f(A-B) and f(A + B) are not perfectly sinusoidal, and must be therefore filtered in order to remove the spurious harmonics, and only retain the components in perfect quadrature relatively to the Coriolis forces.

This result is achieved according to the invention by means of a novel and simple filter based on the Fourier transforms.

In fact, as known, when a sinusoidal signal whose phase and frequency are known, is perturbated by overlapping noises having frequencies multiple of the sought signal, this latter can be isolated and extracted by simply computing the Fourier coefficient relevant to the sought frequency, viz.:

$$A-B = \int_0^{nT} f(A-B) . \cos(2\pi t/T) . dt \qquad (11)$$

wherein T is the period r ferred to the frequency of forced oscillation of the pipe, and $\underline{n}$ represents the number of oscillations during which the integration of the initial signal f(A-B) is carried out.

Unfortunately, the practical embodiment of (11), although makes it possible an actual insensitivity to the phase displac m nts and to the presence of higher harmonic oscillations to be achieved, results too complex, and hence exp nsive both whether means of analog type, or means of digital type, ar adopted.

This impasse was overcome according to the present invention by replacing equation (11) with an approximate r lationship. More specifically, in (11) equation, th function cos $(2\pi.t/T)$ is discretized and comput d for time intervals $\Delta t = T/6$, so that it becomes cos $(i.\pi/3)$, wherein the index number $\underline{i}$ has values comprised within the range of from 0 to (6n-1), in order to cover the whole range of integration time nT. On the other hand, as the above-said values which are assumed by the cosinus function are constant, they can be taken out of the sign of integral, so that equation (11) becomes:

$$(A-B) = \sum_{i=0}^{6n-1} \cos(i.\pi/3).1/4T \int_{i.T/6}^{(i+1).T/6} f(A-B).dt \qquad (12)$$

wherein the concept of summation of a set of integrations, each over a range of T/6 (in fact, when the index $\underline{i}$ becomes (6n-1), the upper integration limit (i+1).T/6 equation (12) becomes equal to nT of equation (11).

It is clear that such a discretization obviously renders less accurate the integral, but, by increasing the number $\underline{n}$ of the integration periods, it is possible to decrease this inaccuracy, up to obtain quite acceptable results.

Summarizing, equation (12) is an approximate relationship, wherein to one single integration of the product of two variable functions, the summation was replaced of a set of integrations of one single function, which is multiplied by the constant values which the cosinus function assumes every π/3rd of period. The cyclic sequence of said values with increasing $\underline{i}$ values is 1; 0.5; -0.5; -1; -0.5; 0.5, according to the broken line of Figure 11.

In practice, the filter is substantially constituted by an analog integrator 28 (see Figure 9), to the input of which the signal f(A-B) is sent, which is available in 26, after that it is cyclically multiplied, in the block 29, by the values of the above cited sequence, under the preliminary command, through the connection 30, by a sequencer 31, which receives the basic synchronization for all of the operations carried out by the system, from a voltage-frequency converter 32 through the connection 33, and defines, through the connection 34, the number $\underline{n}$ of the oscillations, at the end of which the integration in 28 is terminated.

At the end each integration step, during the time interval, e.g., of from t_0 to t_1, at the output 35 of the integrator 29 an integrated signal is therefore obtained, which will be called "U", and which represents the average value of the quantity (A-B) during the time period taken into consideration (see the first chart of Figure 13), but not yet the value of the weight flow rate to be determined, which is obtained, on the contrary, at the specific frequency of twisting resonance of the system, the search for which causes changes in U.

A similar filtering is envisaged for the signal f(A+B) too, which is available at output 27, which is therefore multiplied, in the block 36, by the values of the sequence therein preset, and cyclically made available on command by the said sequencer 31, through the connection 37, and is then integrated in an integrator 38 over the time relating to the $\underline{n}$ oscillations preset by the same sequencer 31, through the connection 39.

The signal, filtered and proportional to the amplitude (A+B) of the flexural oscillation of the pipe, which is available at the outlet 40 of the integrator 38, is then compared to a set signal, preset through the generator 41, in a PID regulator, 42, which thus supplies, at its output 43, a pulsating command signal, whose frequency is imposed by the said voltage-frequency converter 32 and whose amplitude modulates, through the amplifier 44, the impulse energy to be supplied to the excitation coil 10 of the impulse-force-generating electromagnet 9, such to keep constant the above said amplitude (A+B) of the flexural motion of the vibrating system.

The search for the frequency of twisting resonance of the system is then made substantially coincide, according to the present invention, with the search for the frequency which maximizes the amplitude (A-B) of the twisting oscillation of the pipe, and therefore, summarizing, with the search for the frequency which maximizes the above said U signal available at the output 35 of the integrator 28.

In Figure 12, the curve is shown, which represents the behaviour, with the flow rate being constant, of the signal U with varying oscillation frequency f, which shows a maximum peak in correspondence of the frequency of twisting resonance f_{rt}.

It being stated in advanc that th r sonance p ak is actually not like the peak shown in Figure 12, but

much sharper than that, so that a small deviation from the frequency of twisting resonance would cause large variations in U, and, therefore, large errors in the measurement of the flow rate, so that it is necessary that the frequency is always stabilized on th value of twisting resonance, the search of the maximum peak is accomplished by periodically supplying small constant variations, δf, to the impulse-force-generating frequency, measuring the variations ΔU deriving from such variations, such to detect the tangent $\Delta U/\delta f$ to the signal amplitude-frequency curve, and changing, on the basis of the sign and of the value of such tangent, the frequency of oscillation, by increasing, or decreasing, this latter, by a value Δf, which is proportional to the value of said tangent $\Delta U/\delta f$. More specifically, the impulse-force-generating frequency is increased every second period, by a constant value δf, whose behaviour with time is shown by the broken line shown in the second chart from up downwards of Figure 13, and the results U of two successive integrations carried out by the integrator 28 are loaded to two distinct storage devices 45 and 46, which are alternatively enabled to perform the storage by a switch 47 governed by said sequencer 31 through the connection 48.

Now then, at the end of the time t_1 (see specifically Figures 12 and 13), the integrator 28 supplies the output 35 signal U_1, which corresponds to the value of (A-B) which is obtained when the oscillation frequency if f_0, a signal, which, through the switch 47, is loaded to the storage 45 on command by the sequencer 31. During the subsequent time period, until t_2, the oscillation frequency is increased by δf, and goes to value f_1, and the corresponding integrated value U_2 is loaded to the other storage device 46, still on command by the sequencer 31. The contents of the two storage devices 45 and 46 are then subtracted from each other in the node 49, to obtain, at output 50, a signal ΔU, which represents the change in amplitude (A-B) generated by the change δf in the oscillation frequency. Said signal ΔU is then multiplied in the adapter 51 by a constant $K/\delta f$, in order to obtain the value, with the proper sign, of the tangent $\Delta U/\delta f$, which represents the amount of the change

$\Delta f_1 = K.\Delta U/\delta f$

to be supplied to the frequency of oscillation f_0 during the next periods t_3 and t_4 (see the third chart, from up downwards, of Figure 13).

Making the oscillation frequency vary by a so-computed value Δf, makes it possible to optimize, and speed up the reaching of the maximum peak of the signal U, in that the variations Δf result to be large when the impulse-force-generating frequency is far away from the twisting resonance, and the smaller, the smaller the difference between said impulse-force-generating frequency and the frequency of twisting resonance (because, the smaller the difference between said impulse-force-generating frequency and the curve peak frequency, the smaller the value of the tangent: see figure 12).

Said analog value Δf_1 generated in the adapter 51 is then sent to increase the contents, also of analog character (which, at the considered point in time, corresponds to f_0), stored in storage device 52, but always at the end of each second period, i.e., at time points t_2, t_4, t_6, etc., on command by the sequencer 31 through the connection 53 (the behaviour with time of the level of the contents of said storage device 52 is displayed by the third chart, from up downwards, of Figure 13). The output signal from the storage device 52 is then sent, through the addition node 54 and the connection 55, to the said voltage-frequency converter 32, which converts it into a frequency f_2, to be sent, via the connection 33, to the PID unit 42, to modulate in frequency the signal governing the circuit 10 of excitation of the impulse-force-generating magnet 9, as well as to the sequencer 31, to supply the basic synchronization of all of the operations.

Then, by oscillating at frequency f_2, the system will supply, at outlet 35, the new signal U_3 (see Figure 13), which will be stored in said storage device 45.

On the other hand, to said addition node 54 also sent is, on command by the sequencer 31, through the connection 56, the above mentioned small analog signal δf generated by the disturbances generator 57, and whose behaviour is displayed by the broken line shown in the second chart, from up downwards, of Figure 13. In such way, at time point t_3 (see still Figure 13), the two signals as displayed by the second chart and by the third chart of Figure 13 are added to each other, thus generating a new frequency f_3, as shown by the fourth chart of Figure 13, which substantially shows the behaviour with time of the frequency available at the output of the converter 32, with which the force causing oscillating system to oscillate is generated, in correspondence of which a new signal U_4 will be generated, which will be stored in storage device 46. At this time, the previously described cycle is repeated, with a new value Δf_2 being determined, and, consequently, a new oscillation frequency f_4 and a new signal U_5 being defined, and so on.

The result of the above said perations, with a few repetitions, is that the frequency corresponding to the peak M of the curve of Figure 12 is reached and maintain d, wherein the tangent $\Delta U/\delta f = 0$, the output magnitude is maximum, and the oscillating frequency is the twisting resonance frequency f_{rt}.

But, in practic , th increments δf cannot be so small as to secure that the peak M is approximated without going beyond it. The actual sharp curvature of the top of the p ak causes, actually, as shown in

Figure 12, wherein the increase δf in the frequency f_4 leads to a frequency f_5 beyond the frequency of twisting resonance f_{rt}, the operating frequency to fall, due to the effect of the variations δf, now before, and now beyond the twisting resonance frequency f_{rt}, with the result that ΔU practically never results equal to zero, and hence the output signal U oscillates aroung the maximum value.

In order to minimize the error in output, due to the above said drawback, to the actual output 58 of the instrument, the greater value is supplied, of the two available output signals, which are obtained with, and without the disturbance signal δf at each cycle of two integrations for peak search for. In other terms, the contents of the two storage devices 45 and 46 are sent, through respectively the connections 59 and 60, to a selector of maximum value 61, which thus delivers to the output 58 always the greater of the two values available from said storage devices. In this way, even if, during the seach for the peak, some U values result to be lower than the peak value, these values have no influence on the output, but are only used to the end of the search for the frequency of twisting resonance.

On the other hand, in order to have in 58 a zero output signal with a zero flow rate, from the selected output signal 62, in the node 63 a signal is subtracted, which physically corresponds to the said differential action performed by the magnetic brakes 15 and 16, such signal being supplied by a signal generator 64, which is also used for calibrating the instrument.

The above disclosed circuit for searching for, and maintaining, the frequency of twisting resonance is substantially simple and perfectly efficient until the flow rate of the fluid under measurement does not change too quickly.

In case of quick changes in flow rate, conditions may occur, under which the circuit does not correctly operate, with the result that, for some time, i.e., before the flow rate reaches a steady state, the impulse-force-generating frequency may not correspond to the frequency of twisting resonance.

The mechanism by which an error can occur in the processing of the frequency corrections when the flow rate changes quickly can be easily understood in such a case as shown by Figure 14, wherein several curves are reported, which are characteristic curves for U signals as a function of frequency, and referred to different flow rates Q_1, Q_2 and Q_3, which are hypothesised to rapidly follow each other during time.

In fact, it is evident that, in particular at frequency f_0 with flow rate Q_1, the output signal is U_1 (the "a" point of Q_1 curve of Figure 14), when the frequency is increased by δf, i.e., when the frequency is increased to the new value f_1, the magnitude of the new output signal, instead of increasing like it would do, if the flow rate had remained constant (the "b'" point of curve Q_1), decreases, reaching the U_2 value, because the flow rate decreased to Q_2 (the "b" point of Q_2 curve). The circuit for the search for the resonance frequency computes, under these conditions, a correction to be supplied to the frequency, having the value of $\Delta U = \Delta U_2 - U_1$, which, by being negative, clearly causes the frequency to depart from the sought twisting resonance frequency f_{rt}.

In order to obviate such drawback, still according to a characteristic of the instant invention, a variant of the above disclosed circuit was developed, which makes it possible the twisting resonance frequency to be pursued even when the flow rate changes rapidly.

According to this variant, no longer two-period cycles are taken into consideration, but three-period cycles are considered, so that the analog signal δf which is used is no longer that as shown by the second chart from up downwards of Figure 13, but the signal represented in the second chart from up downwards of Figure 15, i.e., the increase δf is added to the operating frequency every third period. The analysis is hence carried out on three successive values of U signal, and, precisely, e.g., on the signal U_1 corresponding to the f_0 frequency and at the flow rate Q_1 (see Figure 14), on the subsequent value U_2 obtained at the frequency $f_2 = f_1 + \Delta f$, and at the flow rate Q_2, and at a third value U_3, obtained by bringing the system impulse-force-generating frequency back to the initial value it had at cycle beginning, i.e., to f_0 (see the fourth chart, from up downwards, of Figure 15), with the flow rate being become Q_3 (the "d" point of Figure 15).

Now, one should remind that the above said two values U_1 and U_3, obtained at the same frequency, are very different from each other, whilst they would be the same if the flow rate had been under steady state conditions. Now then, the method developed according to the present invention consists in applying to the basic frequency f_0 a correction Δf_1, which is not proportional to the difference between the second measured value U_2, and the first value U_1, but is proportional to the difference between said second measured value U_2 and the average value of the values U_1 and U_3, as computed at the same frequency f_0, and at the flow rates Q_1 and Q_3. In other terms, an approximate value is substantially computed, of the actual tangent to the curve corresponding to the flow rate Q_2 in the considered area, which is represented by the tangent of be angle (see Figure 14), viz.:

$$\tan\alpha \simeq \frac{\overline{be}}{\delta f} = \frac{U_2 - (U_1 + U_3)/2}{\delta f}$$

It should be also observed that the above said approximation the better, the more regular the chang in flow rate, up to even coincide with the correct value in case of equidistance of the relevant curves at flow rates Q_1, Q_2 and Q_3.

In the actual case of a not regular variation, as shown, e.g., in Figure 14, the above said approximate value shows the advantage that it at least shows the advantageous characteristic that the tangent has the correct value, and hence generates such a correction Δf_1 to be supplied to the oscillation frequency, that an approaching to the resonance peak, and therefore to the twisting resonance frequency f_{rt}, is anyway obtained.

From the view point of the electronic circuit, the above disclosed variant consists in simply replacing the circuit portion 76 of Figure 9 with the circuit portion shown in Figure 10, wherein a third storage device 77 is provided, which is designed to store, through the above said, now three-way, switch 47, the signal U_3 available at the output of the integrator 28 during the third period of the cycle.

The two storage devices 45 and 77 are then connected to the addition node 78, to obtain at output 79 the value $(U_1 + U_3)$, which is divided, in the divider 80, by 2, to obtain, at output 81, the average value $(U_1 + U_3)/2$ which shall be used, as said, for computing the approximate tangent by means of the difference node 49 and of the adapter 51, which have already been disclosed for the basic circuit.

Then, analogously to as provided for the basic circuit, in this case too, a selector of maximum value 81 is provided for, to which the contents of all of the three storage devices 45, 46 and 77 are sent, in order to select the largest among the detected U values.

In Figure 2, for exemplifying purposes a practical embodiment of a flowmeter according to the invention is shown, which consists of an individual rectilinear pipe 65, through which the fluid flows in the direction of the arrows 1, and is made oscillate at the frequency corresponding to the frequency of resonance with its second harmonic 3 (see specifically Figure 8), by the impulse-force-generating electromagnet 9 acting on the middle of the pipe.

Such a flowmeter, whose advantages are clearly evident, both from the viewpoint of minimizing the pressure drops, and from the viewpoint of minimizing the costs and the structural complications, in particular as relates to the problems of centering and alignment, is provided, besides the true oscillating pipe 65, with a second pipe 66, external to, and coaxial with, pipe 65, which performes the double task of connecting the two connection flanges 67 and 68 and of supporting the impulse-force-generating electromagnet 9 and the two electromagnetic brakes 15 and 16, respectively equipped with the B motion sensor, 17, and with the A motion sensor, 18, both of which have the same structure, and the same function, as of the corresponding sensors as used for the portal-shaped pipe 4.

Then, in as much as this flowmeter type is particularly indicated for large-size pipes, wherein the necessary impulse-force-generating power may become considerable, according to the present invention a contrivance was found, which is suitable for considerably reducing said power, and the corresponding dimensions of the impulse-force-generating electromagnet.

Said contrivance consists in connecting the external pipe 66 to the internal pipe 65 in a point lined up with the axis of the impulse-force-generating electromagnet 9, by means of an elastic metal membrane 69, i.e., by means of an elastic component, which is capable of increasing the overall elastic constant of the system formed by the pipe and its constraints, such to increase the value of the resonance frequency with the first harmonic (equivalent to the flexural resonance oscillation). In fact, in as much as this additional contrivance is positioned exactly in the middle of the pipe, and, hence, in correspondence of the node 70 (see Figure 8) of the resonance oscillation of the second harmonic (equivalent to the twisting resonance oscillation), its presence does not lead to any changes in the resonance frequency of this second harmonic, although it modifies the first harmonic thereof. On the other hand, by suitably selecting this additional elastic constant, it is possible to cloesely approach the resonance frequency of the first vibrational mode (the first harmonic) of the pipe to the resonance frequency of the second vibrational mode (the second harmonic), so that, with the control of the motion being still carried out in such a way as to perform the search for the resonance frequency corresponding to the second harmonic, the necessary impulse-force-generating power will be much lower, because the pipe already oscillates at a frequency in the nearby of its own frequency of spontaneous resonance (the flexural resonance frequency) corresponding to the first harmonic.

Finally, a further advantage of this form of practical embodiment with a rectilinear oscillating pipe is

given by the fact that the flowmeter can be made immune from the seismic disturbanc s, with no need for elastic supports, because the instrument can be supported by the same connection flanges 67 and 68, with which it does not interact, on condition that it has been so dimension d, that the external pipe oscillates in the opposite direction as compared to the inner pipe, with no flange rotation. To this end, it is enough that the stiffness of the internal oscillating pipe, and the stiffness of the external support pipe, to which the magnetic brakes and the impulse-force-generating electromagnetic are fastened, are, relatively to each other, in a ratio proportional to the ratio of their respective masses.

In this way, in fact, by making the system forcedly oscillate at a frequency higher than the own resonance frequency of each of said two pipes, the oscillations of said two pipes shall take place in mutual opposition of phase, and hence with zero rotation of the flanges, in as much as on them the flexural torques of the two systems are equal to each other, and mutually annihilate; furthermore, the barycentre of the system, due to the fact that the two masses move in mutual opposition of phase, practically remains stationary, hence, with the result that no interactions exist with the external environment. The limit of this configuration is however given by the need of matching the external mass to the mass of the fluid under measurement, so that, when this latter changes to a considerable extent, restrictions must be provided for in the geometries, and in the supports for the pipes entering the system such to render repetitive and controlled the interactions, in as much as also they become to form a part of the oscillating system.

But, by simply doubling the pipe and the tube, and causing them to oscillate in opposition of phase, always at a frequency coincident with the second harmonic, and therefore consequently increasing the costs and the structural complexity, is anyway possible to obtain a measurement system which is practically insensitive both to the changes in the mass of fluid, and to the geometry of the connection pipes.

In Figure 16, a further type of flowmeter, also according to the invention, is shown, which shows such a double rectilinear pipe 71 and 71', and which adopts an original solution for the assemblage of both the magnetic brakes 15 and 16, and the impulse-force-generating electromagnet 9.

This assemblage solution makes it possible the double outcome to be obtained, of reducing the overall dimensions, with the action being the same, of both the sensor-brake assemblies, and of the exciter, or impulse-force-generating, electromagnet, by increasing their lever arm, as well as of lightening the moving parts, in that the above-said magnetic elements are rendered stationary, and not connected to an oscillating support.

Summarizing, the support device for each one of the above-said three magnetic units substantially consists in a lever 72 (see also Figure 17), connected at an end 73 to the movable member of the electromagnet, or of the brakes, and, at its other end, with the upper pipe 71' and with the lower pipe 71, respectively through the elastic blade 74 and the two elastic blades 74' and 74", connected to one another by a stiffening plate 75, with the two sets of blades 74 and (74', 74") being located very close to each other.

The amplification of the motion and of the forces results thus to be proportional to the ratio of the length of the lever 72, to the distance between the two sets of elastic blades, which also perform the function of supporting the same lever, whilst the stationary bodies of the brakes 15 and 16, and of the electromagnet 9 can be mounted on a separate stationary support.

By means of this system, it is easily possible to achieve a 100^{x} amplification, and, consequently, a considerable reduction, with the action being the same, in the dimensions of the above said magnetic units.

Claims

1. Process for the measurement of the weight flow-rate of a fluid, consisting in making the fluid to be measured outflow inside a duct, or a pipe fastened, at its ends to a support, and made oscillate at a certain frequency, and with a constant amplitude, or with an amplitude controlled by an impulse-force-generating device, and in measuring the deformations caused on the pipe by the Coriolis forces, characterized in that it comprises the steps of making said pipe oscillate, and keeping said pipe exactly at its twisting resonance frequency, of counteracting the said oscillation of the pipe with at least a couple of brakes, performing a braking action which is proportional to the speed of pipe shifting, and with a braking intensity which is larger than the action performed by the said Coriolis forces, of detecting the pipe shifts in two points thereif which are symmetrical relatively to its centre, wherein the largest twisting deformation occurs, and finally of determining, as the measure of the weight flow rate, th diff rence in the amplitudes of the above-said two shifts, with th preliminary r moval, by means of a filtering, of the disturbances due to the supply of the pulsating force, or of seismic origin, or deriving from misalignments.

2. Process according to claim 1, characterized in that the above said dampening action of the oscillation of the pipe is achieved by means of at least a couple of brakes having a differentiated braking effect, i.e., with a larger braking effect at the fluid inlet side of the pipe.

3. Measurement instrument, or flowmeter, for the determination of the weight flow rate of a fluid according to the process according to one of the preceding claims, comprising a pipe substantially having a portal shape, fastened at its free ends on two shoulders of a support, and made oscillate by an impulse-force-generating electromagnet acting in correspondence of its middle, characterized in that to the ends of the jambs of the portal, applied are the movable coils of at least two magnetic brakes performing a different braking effect, fastened to said support, as well as the sensors detecting the shifts of the said ends of the portal oscillating at its twisting resonance frequency, said instrument being mounted on an elastic support and being provided, among others, with means for filtering the difference and the sum of the signals relating to said shifts, and thus obtain their amplitude, with means for searching for, and maintaining, said twisting resonance frequency, maximizing the output signal generated by the instrument, both at a constant flow rate, and at a variable flow rate, with means for selecting the maximum value of the output signal, as well as with means for compensating for the different braking effect of the brakes.

4. Measurement instrument, or flowmeter, for the determination of the weight flow rate of a fluid according to the process according to one of the claims 1 or 2, comprising a single rectilinear pipe, fastened at its ends to two connection flanges, and made oscillate by an impulse-force-generating electromagnet acting in correspondence of its middle, characterized in that to the points of the pipe wherein the maximum amplitude of oscillation corresponding to its second harmonic is generated, applied are the movable coils of at least two magnetic brakes performing a different braking effect, fastened to said support, as well as the sensors detecting the shifts of the said two points of the pipe oscillating at the frequency corresponding to its second harmonic, said instrument being provided, among others, with the same means as already mentioned in claim 3.

5. Measurement instrument, or flowmeter, according to claim 4, characterized in that said single rectilinear pipe is internally coaxial with a second pipe connecting the said connection flanges with each other, and acting as a support for the said impulse-force-generating electromagnet and for the said electromagnetic brakes, said second pipe being furthermore connected with the said single rectilinear pipe in a point aligned with the axis of an impulse-force-generating electromagnetic by means of an elastic metal element, e.g., a membrane.

6. Measurement instrument, or flowmeter, for the determination of the weight flow rate of a fluid according to the process according to one of the claims 1 or 2, comprising two rectilinear pipes, which, connected at their ends by means of two connection flanges, are made oscillate by an impulse-force-generating electromagnet acting between them in correspondence of their middle, characterized in that in the points of the pipes wherein the maximum amplitude of oscillation corresponding to their second harmonic is generated, between said pipes applied are the movable coils of at least two magnetic brakes performing a different braking effect, as well as the sensors detecting the mutual shifts in the said two points of the two pipes oscillating at the frequency corresponding to their second harmonic, said instrument being provided, among others, with the same means as already mentioned in claim 3.

7. Measurement instrument, or flowmeter, according to claim 6, characterized in that said impulse-force-generating electromagnet, and the movable coils of the above said two magnetic brakes are applied between said two pipes, each one of them being respectively applied by means of a lever linked at an end to the movable member of said impulse-force-generating electromagnet, or to the coils of said magnetic brakes, and, at its other end, to two elastic metal blades located very close to each other on the end of the lever, and respectively fastened to the two rectilinear pipes.

8. Measurement instrument, or flowmeter, according to claim 3 or 4 or 6, characterized in that the oscillation of the pipe, or of the pipes, is obtained by means of two impulse-force-generating electromagnets acting with equal forces in correspondence of said points of application of said magnetic brakes.

9. Measurement instrument, or flowmeter, according to claim 3 or 4 or 6, characterized in that said shift-detecting sensors are speed sensors conglobated in said electromagnetic brakes.

10. Measurement instrument, or flowmeter, according to claim 3 or 4 or 6, characterized in that the above said filtering means essentially consist of an analog integrator, at the input of which said sum signal and said difference signal relating to said shifts are sent, after these signals being cyclically multiplied by the sequence of values 1; 0,5; -0,5; -1; -0,5; 0,5, on command by a sequencer which provides for the synchronization and for the timing of the duration of the integration.

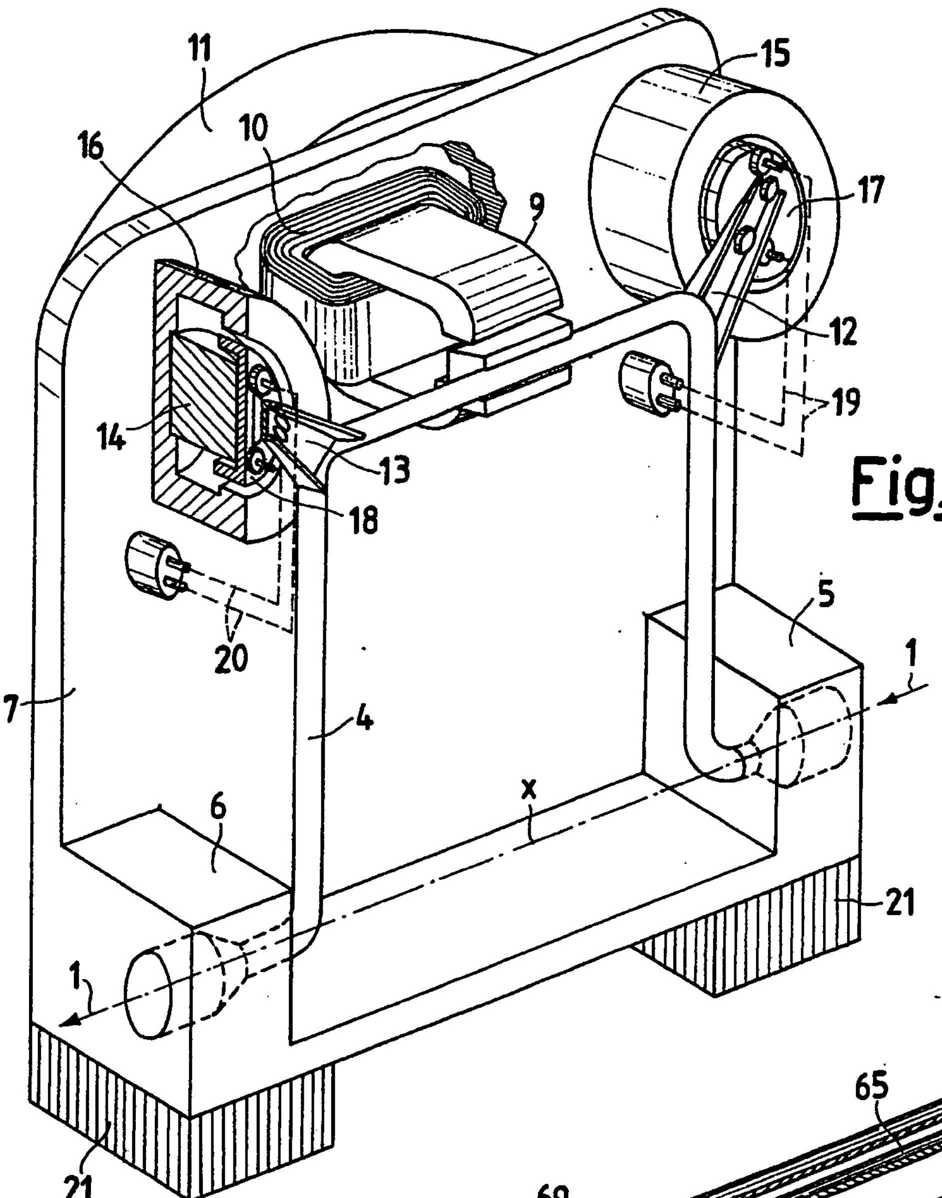
11. Measurement instrument, or flowmeter, according to Claims 3 or 4 or 6 and 10, characterized in that the above said means for searching for, and maintaining said twisting resonance frequency at constant flow rate substantially consist of two storage devices, wherein th results are stored, of two successive

integrations of said analog integrator, through a switch governed by said sequencer, the outputs of said storage devices being sent to a difference node, which is connected with an adapter multiplier by a prefixed constant, in its turn connected with an analog storage device, wherein it accumulates its output value only at the end of every group of integration periods constituted by two periods of integration on command by the said sequencer, which also governs a generator of disturbances, to deliver, every second period, a small analog signal (δf) to an addition node, to which also the output of said analog storage device comes, whilst the output from said addition node is connected with a voltage-frequency converter, whose output is sent to a PID unit, to modulate in frequency the constant-amplitude signal which governs the excitation circuit of said impulse-force-generating electromagnet, as well as to the said sequencer for the basic synchronization.

12. Measurement instrument, or flowmeter, according to claims 3 or 4 or 6 and 11, characterized in that the above said means for searching for, and maintaining the above said frequency of twisting resonance at a variable flow rate, substantially consist of three storage devices, wherein the results are stored, of three successive integrations of said analog integrator, through a switch governed by said sequencer, the outputs from the two storage devices containing the first and the third integrated value being sent to an addition node connected with a divider by two, in its turn connected with the said difference node of claim 11, which is connected with the same elements as indicated in said claim 11, with the only variant that now cycles consisting of three period of integration are taken into consideration, and hence said generator of disturbances sends an analog signal (δf) always and only during the second period of said three periods.

13. Measurement instrument, or flowmeter, according to claim 3 or 4 or 6 and 11 or 12, characterized in that said means for selecting the maximum output consist of a selector of maximum, to whose input the outputs from said storage devices are sent.

14. Measurement instrument, or flowmeter, according to the preceding claims, characterized in that said means for compensating for the differential action of said magnetic brakes consist of a difference node, to which the output from said selector of maximum, and the output from a signal generator are respectively sent.


11
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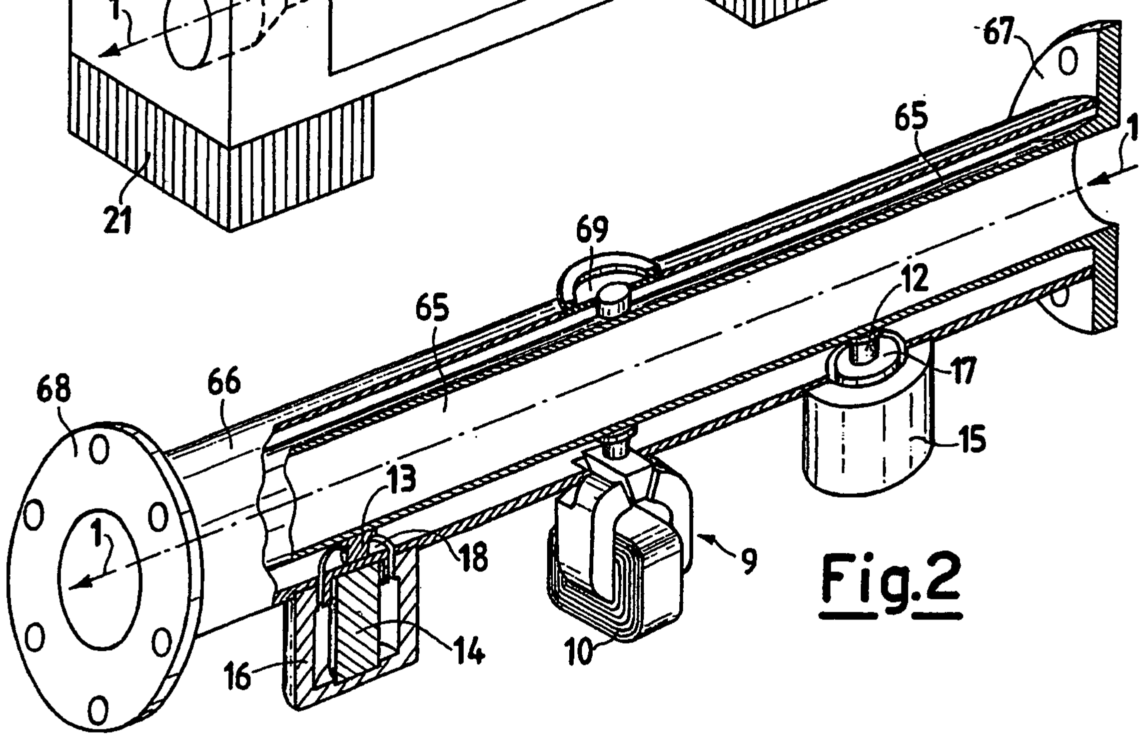
5
1
7
4
6
x
21
1
21

Fig.1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16
10

Fig.2

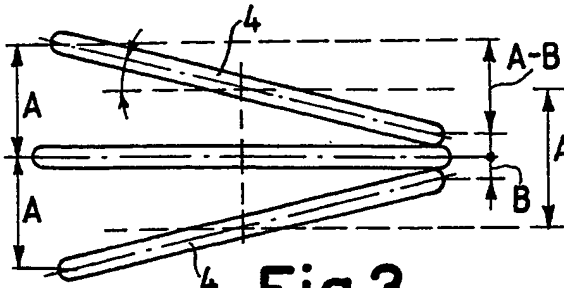


Fig.3

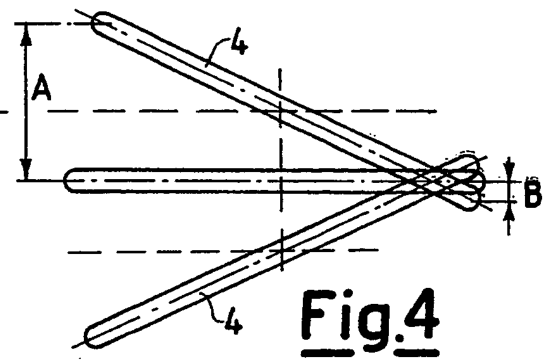
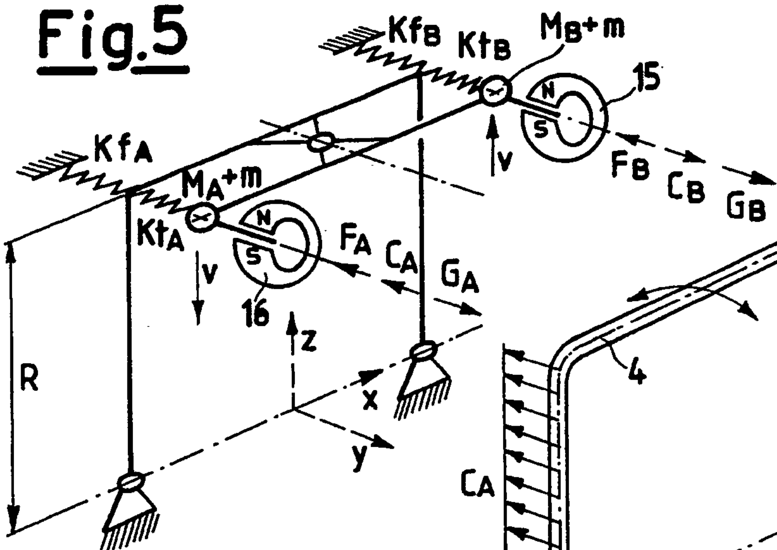


Fig.4

Fig.5



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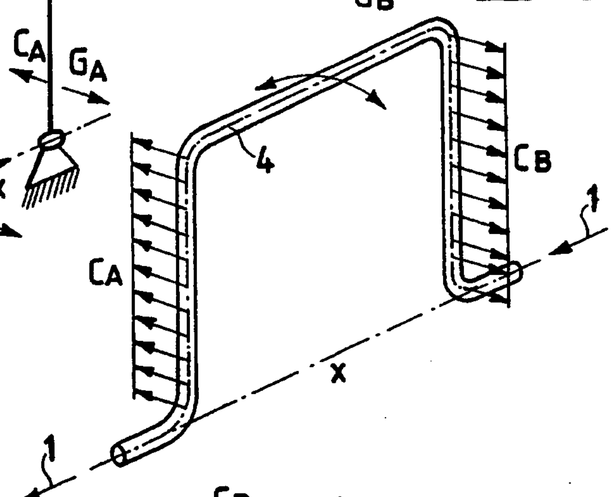

Fig.7

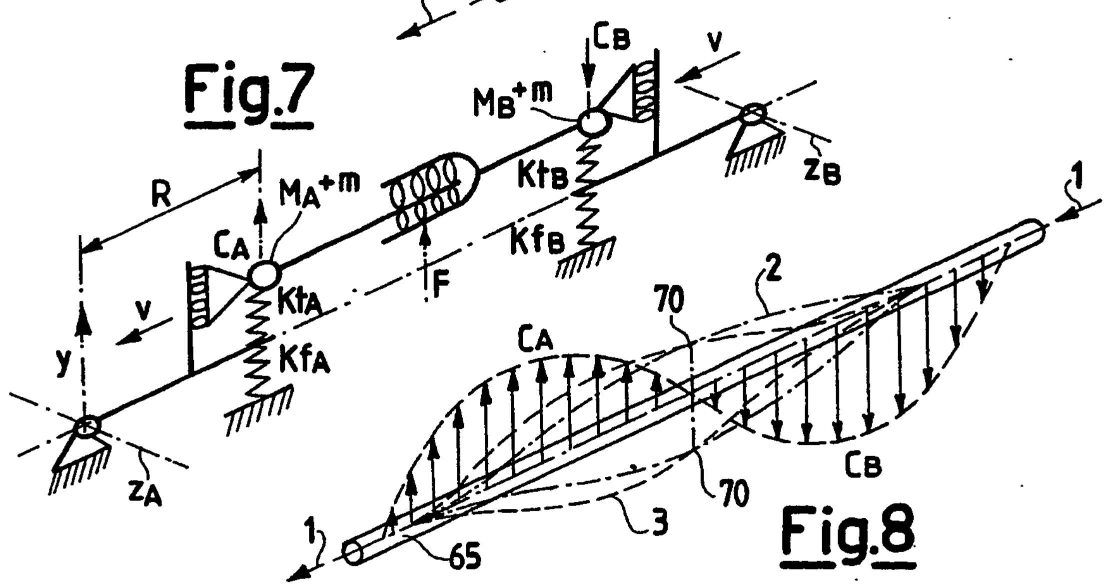

Fig.8

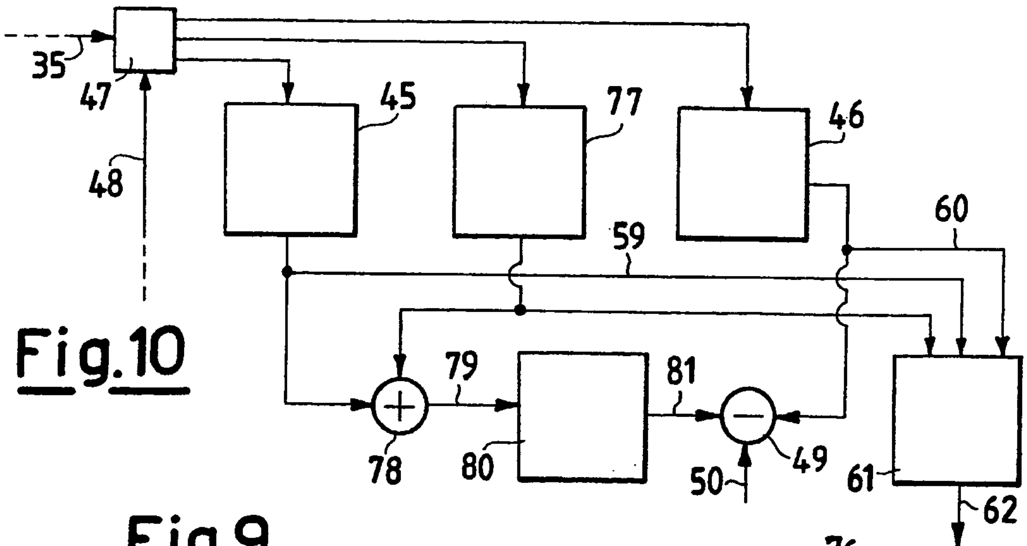
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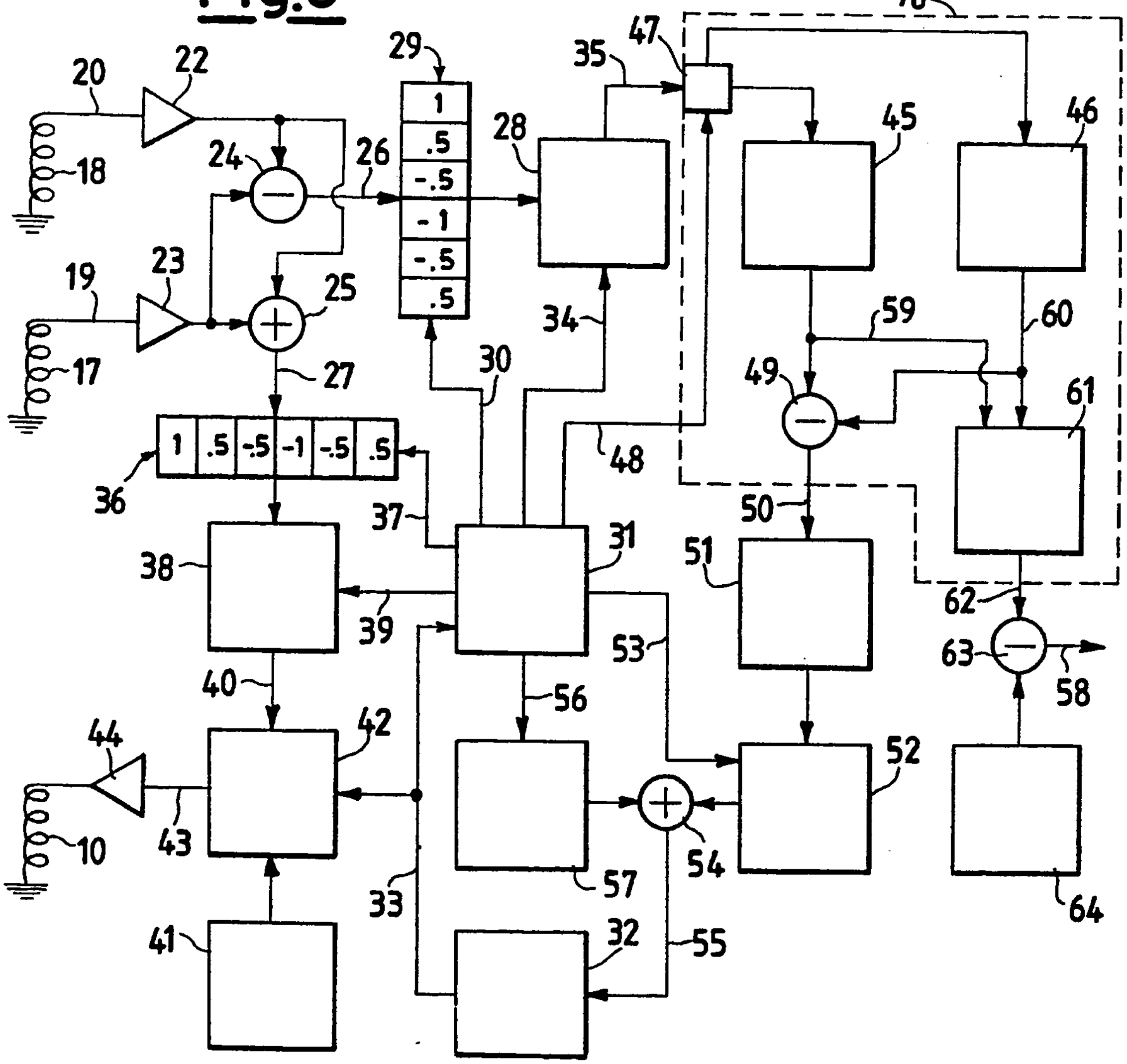
Fig.10

Fig.9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-.5
-1
-.5
.5
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Fig.11

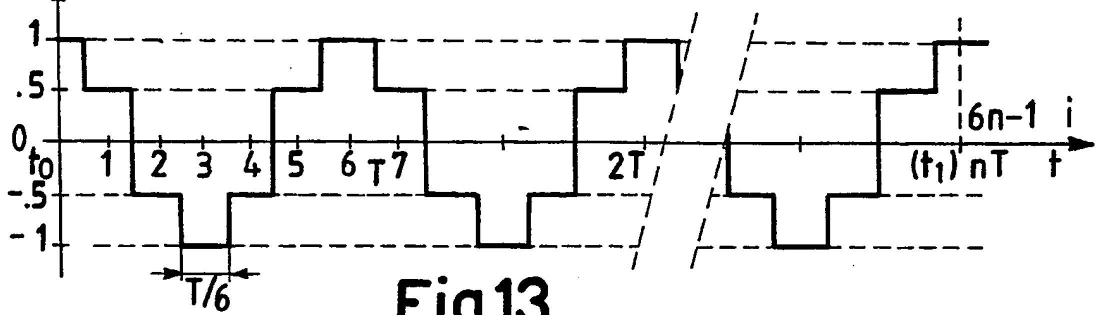


Fig.13

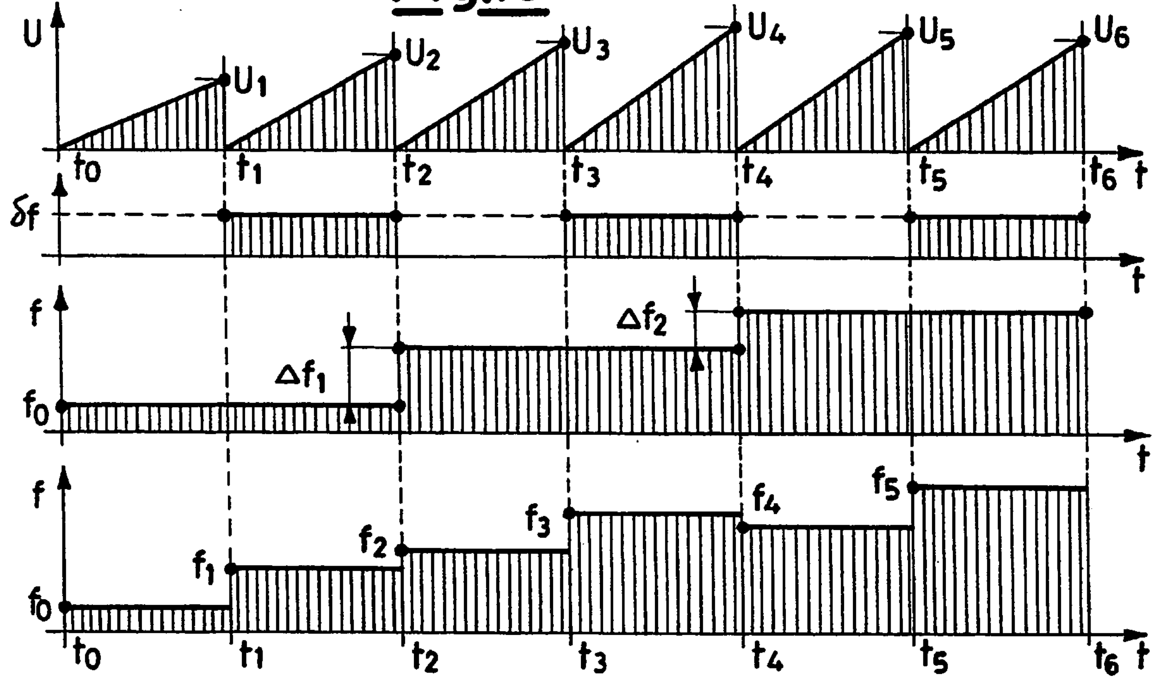


Fig.12

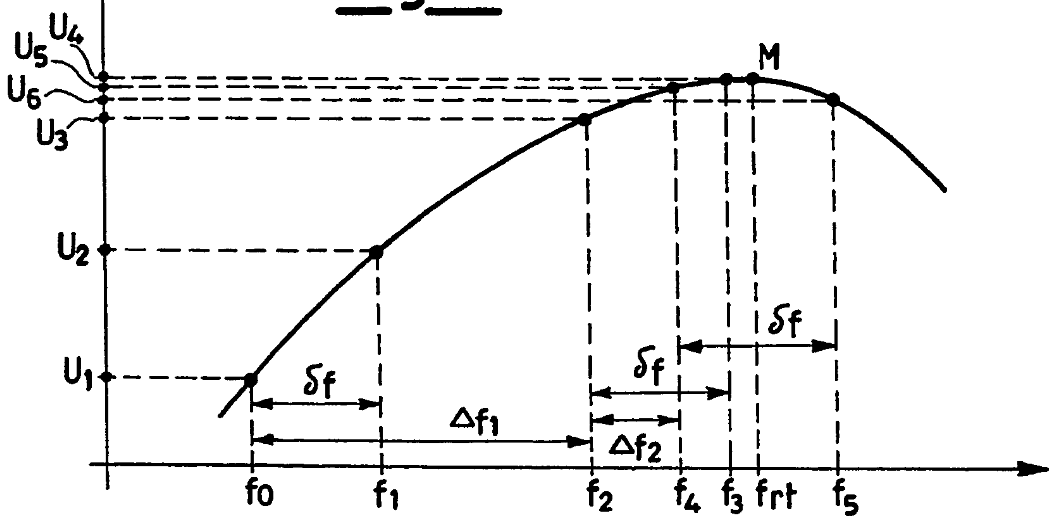
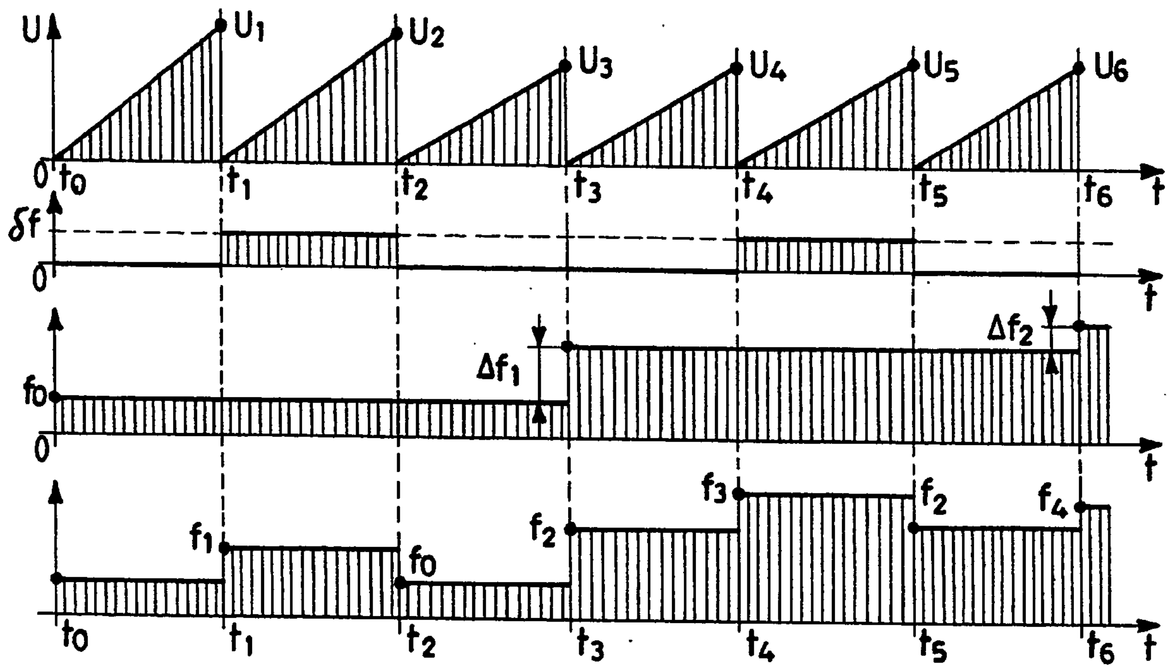


Fig.15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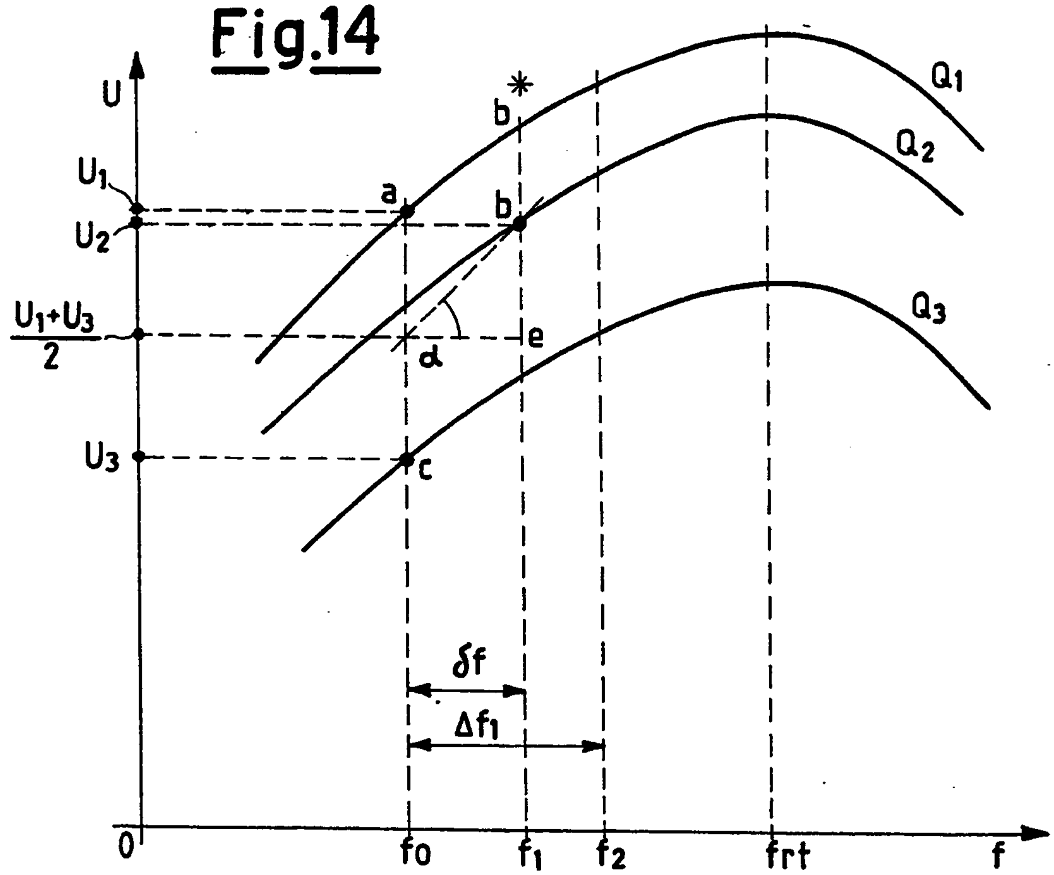
U1
U2
U3
U4
U5
U6
0
t0
t1
t2
t3
t4
t5
t6
t
δf
Δf1
Δf2
f0
f1
f2
f3
f4

Fig.14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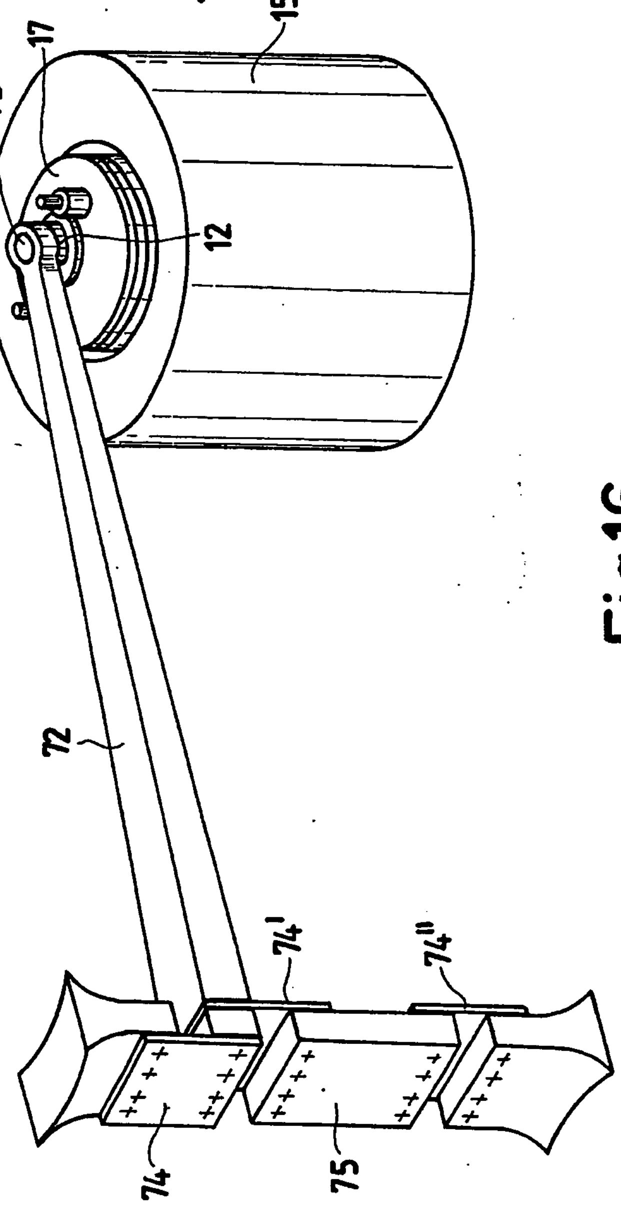
U1
U2
U1+U3
2
U3
0
a
b
b*
c
d
e
α
Q1
Q2
Q3
δf
Δf1
f0
f1
f2
frt
f

Fig.17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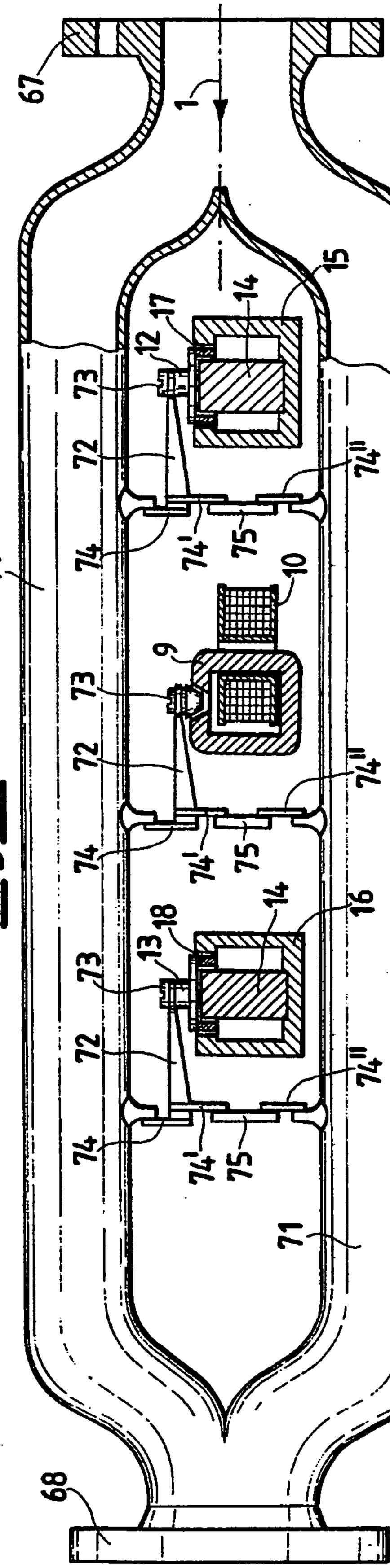
73
12
72
74'
74''
74
75

Fig.16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72
74''
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71'
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71
68